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Representation of the Land Surface in the Regional Arctic System Model (RASM)

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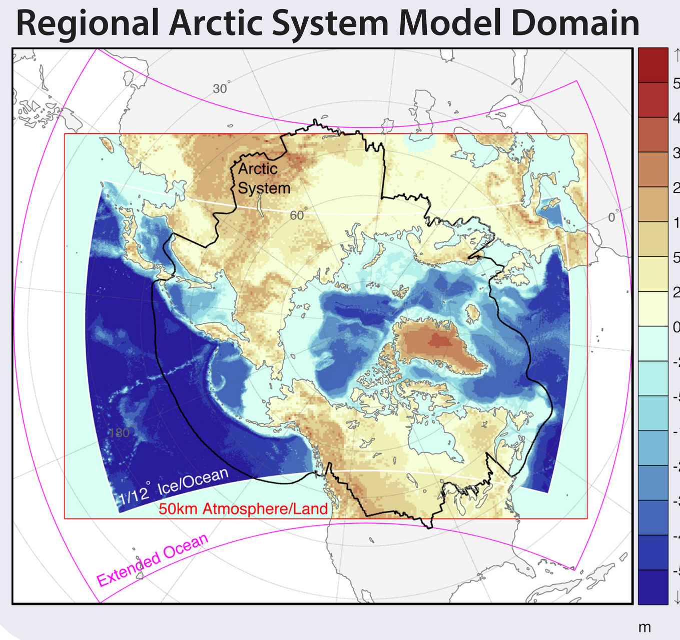
Regional Arctic System Model Domain



Introduction

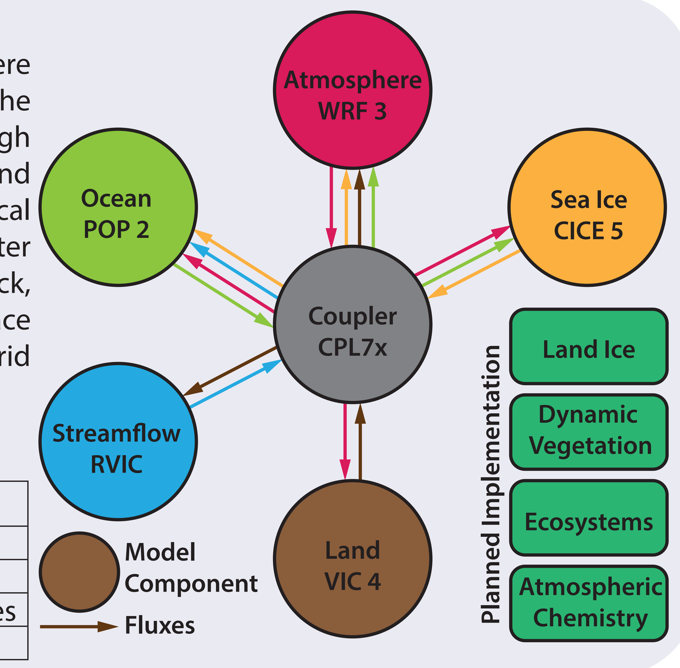
The Regional Arctic System Model (RASM) is a high-resolution regional Earth System Model whose domain includes the entire Arctic drainage basin. The development of RASM is motivated by the objective to advance understanding of the Arctic climate system and to improve decadal climate predictions in high northern latitudes. Land surface processes in RASM are simulated using the Variable Infiltration Capacity (VIC) hydrologic model and the RVIC streamflow routing model coupled within the CESM modeling framework.

Coupled Land Processes

The land surface is coupled to the atmosphere through the exchanges of energy and water. The energy and energy budgets are linked through the latent heat flux. In RASM, the role of the land surface component is to simulate the physical exchanges and storages of energy and water between the atmosphere, vegetation, snowpack, and soil. Distributed runoff from the land surface is routed downstream to individual coastal grid cells where it is delivered to the ocean model.

Model Configuration

Component	Model	Resolution	Timestep
Atmosphere	WRF 3	50km, 40 levels	2.5 minutes
Land	VIC 4	50km, 3 Soil Layers	20 minutes
Runoff	RVIC	50km	60 minutes, distributed every 20 minutes
Coupler	CPL 7x		20 minutes for all components

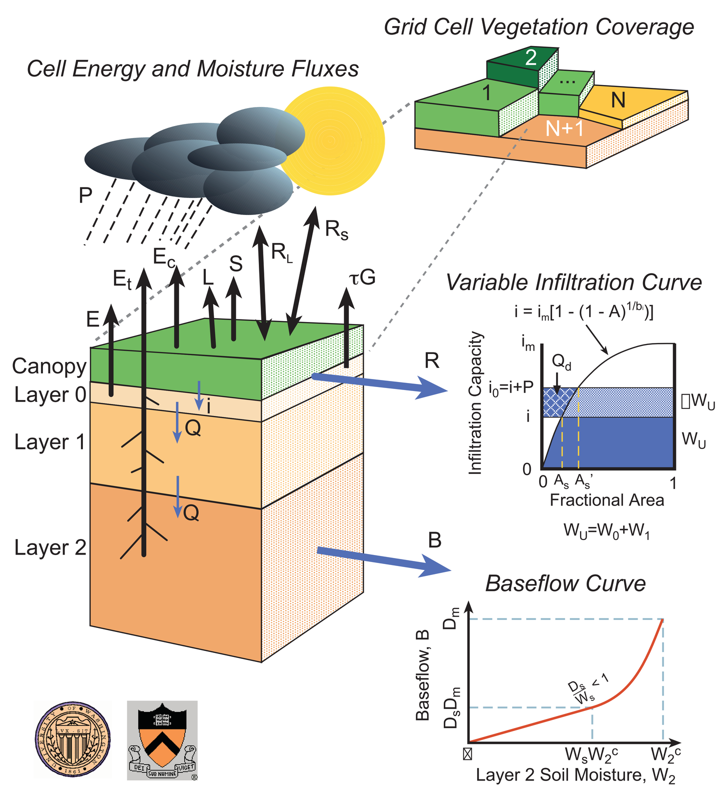


Land Surface Model

The **Variable Infiltration Capacity (VIC)** model is a physically based semi-distributed hydrologic model that solves the water and energy balance equations. Key features of the VIC model are:

- Representation of subgrid variability in vegetation and topography through a statistical tiling scheme,
- Nonlinear distribution of soil moisture and infiltration capacity,
- Nonlinear baseflow recession from the lowest soil layer,
- Representation of cold land processes such as frozen soils and blowing snow.

When run in full energy mode, as it is in RASM, the model iterates in order to close the surface energy balance. This iterative process finds the surface temperature and the associated surface fluxes (latent and sensible heat, outgoing longwave and shortwave radiation, and ground heat and storage).

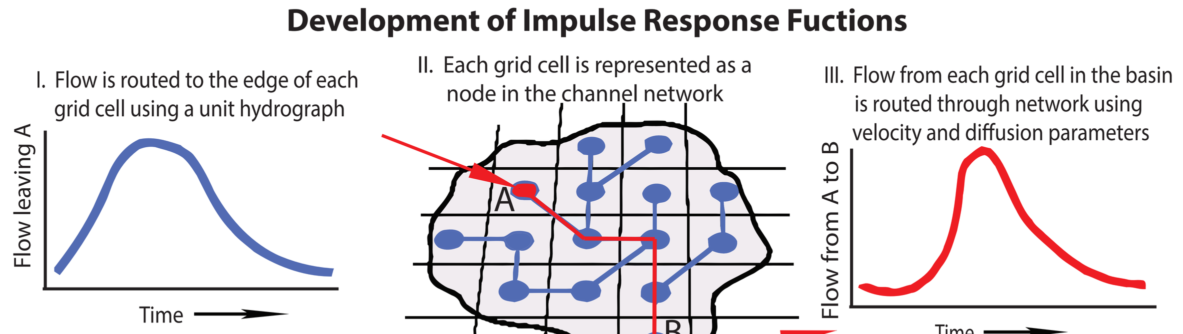


Streamflow Routing Model

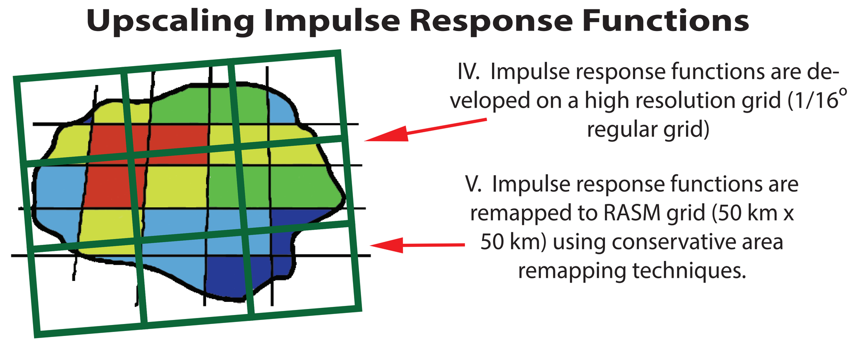
The **RVIC** streamflow routing model is a modified version of the streamflow routing model typically used as a post-processor with the VIC model. The routing model is a source-to-sink model that solves a linearized version of the Saint-Venant equations. Key features of the RVIC routing model are:

- Impulse Response Functions (IRFs or Unit-Hydrographs) represent the distribution of flow for each source-outlet pair.
- IRFs are linear and time invariant.
- Velocity and diffusion parameters can be calibrated.
- Development of the IRFs on a high-resolution latitude-longitude grid, rather than on the land model grid.
- Up-scaling of IRFs to the land grid preserves fine-scale response features present in the high-resolution flow network.
- Development of IRFs is done as a pre-process so that the only step to be completed in the coupled model is the flow convolution.

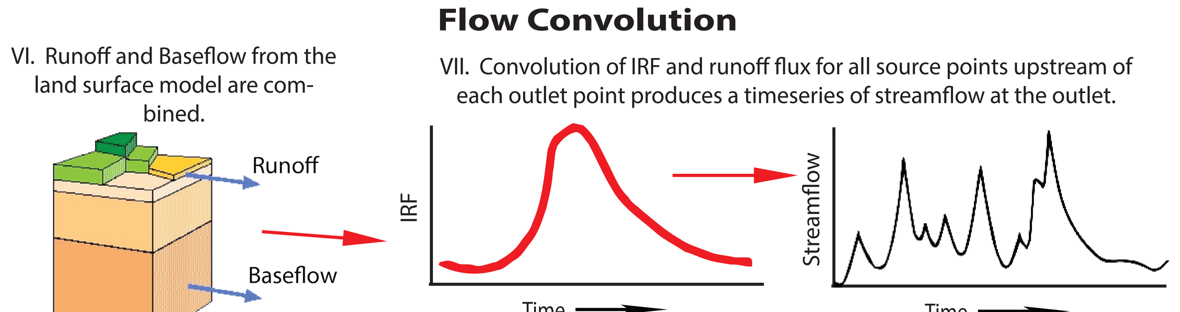
Development of Impulse Response Fuctions

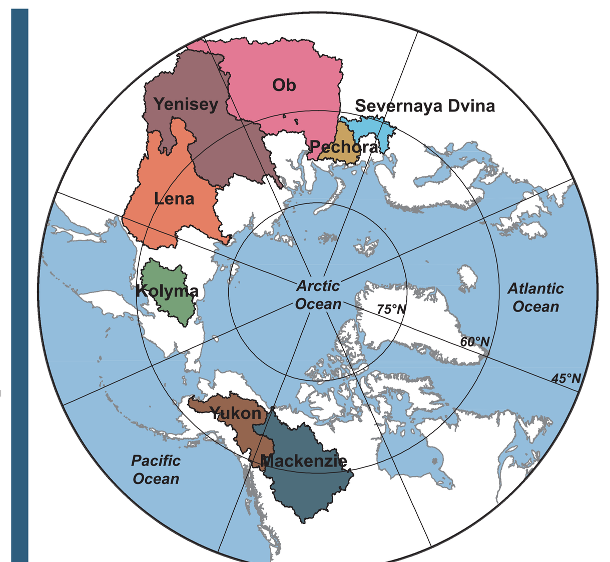


Upscaling Impulse Response Functions



Flow Convolution





Source of Observations:

1. Precipitation: Adam et al. (2006)
2. Runoff: R-ArcticNET V4.0, Lammers et al. (2001)
3. Snow Cover: NSIDC Northern Hemisphere EASE-Grid 2.0 Weekly Snow Cover and Sea Ice Extent, Version 4, Brodzik et al. (2013)

**Shading represent the 25% and 75% percentiles of the seasonal cycle.

The Hydrologic Cycle in RASM

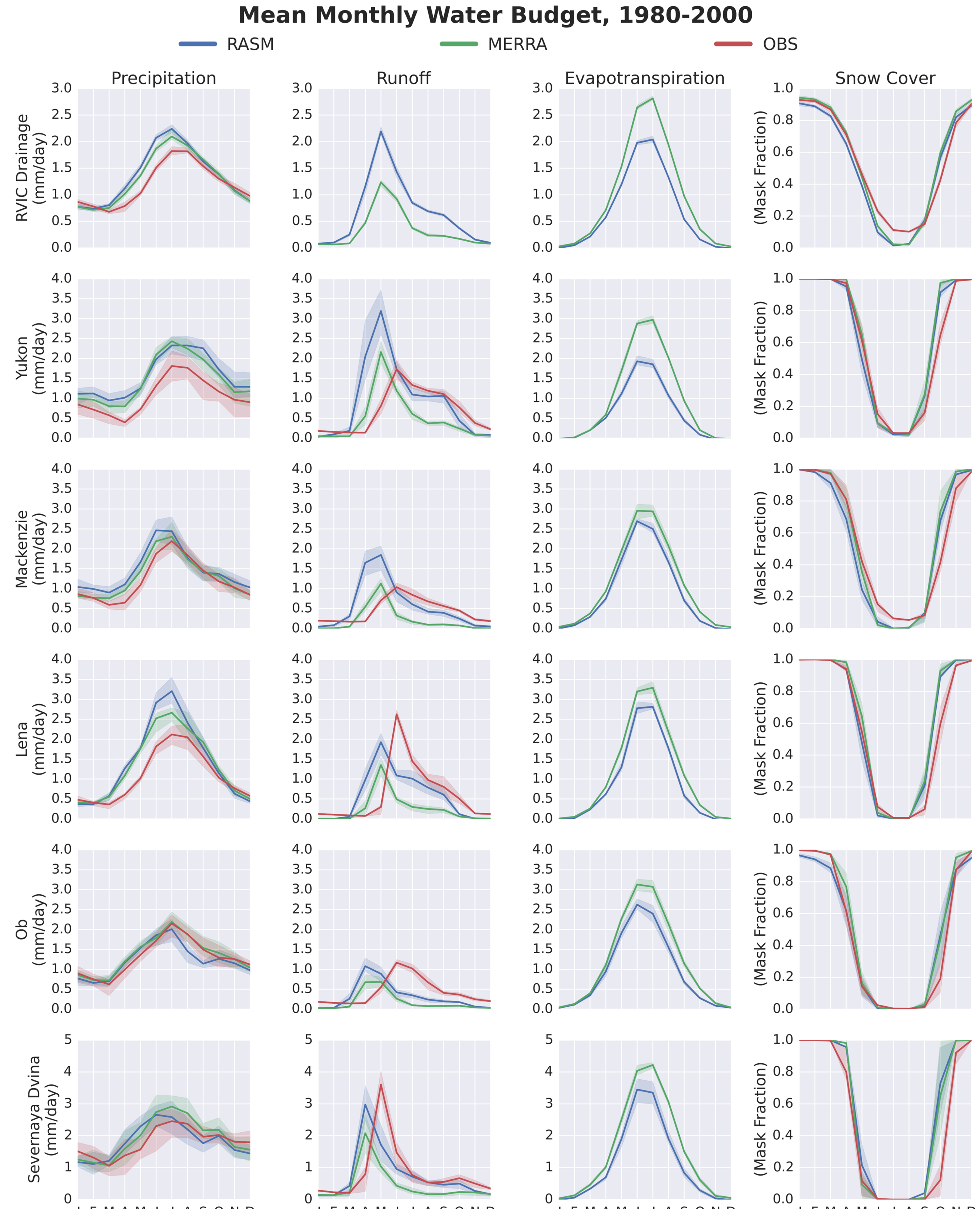
Analysis:

We compare basin averaged mean monthly (1980-2000) precipitation, evapotranspiration, runoff, and snow cover extent between RASM forced with ERA-Interim boundary conditions, MERRA, and a variety of observations. Spatial averaging was performed using the union of the RASM, MERRA, and EASE grid masks. Basin averaged runoff from the R-ArcticNET database was calculated using the effective upstream area.

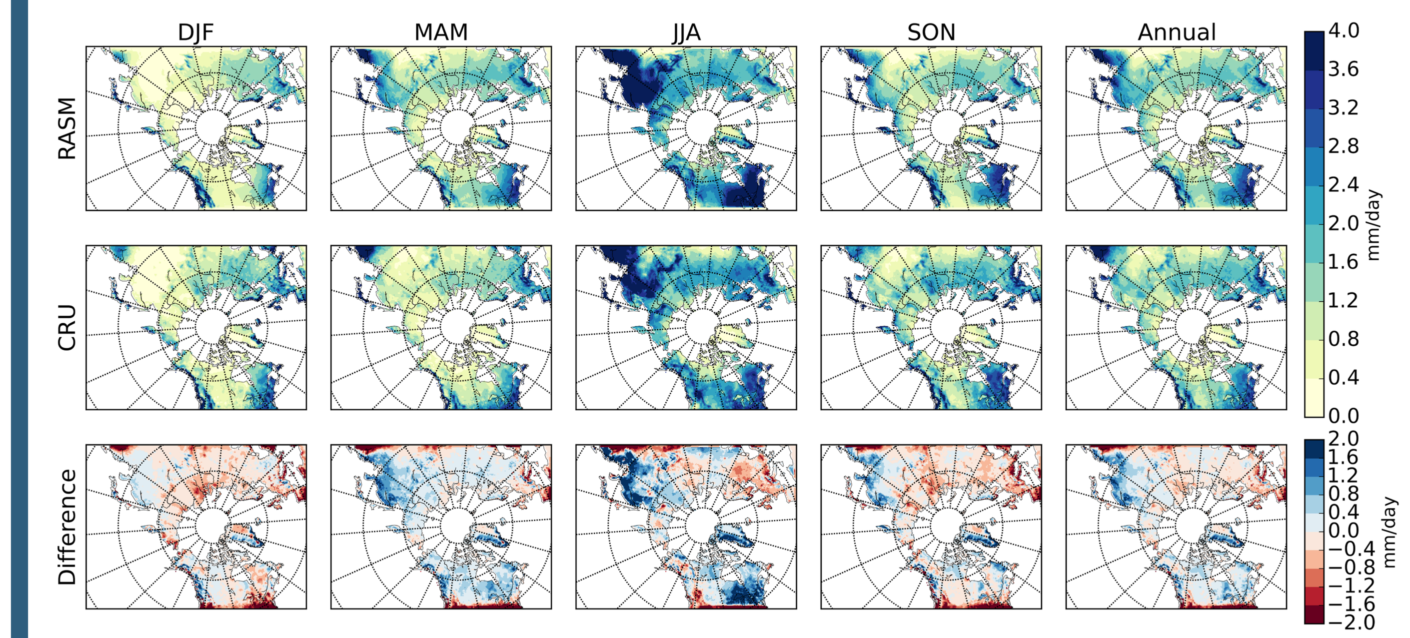
Results:

- RASM tends to have more precipitation than MERRA or the observations, especially in the spring and summer.
- Peak annual streamflow in RASM and MERRA occurs 1-2 months earlier than in the observations.
- MERRA consistently produces more evapotranspiration than RASM.
- The seasonal patterns of snow cover and retreat are well captured by both RASM and MERRA.

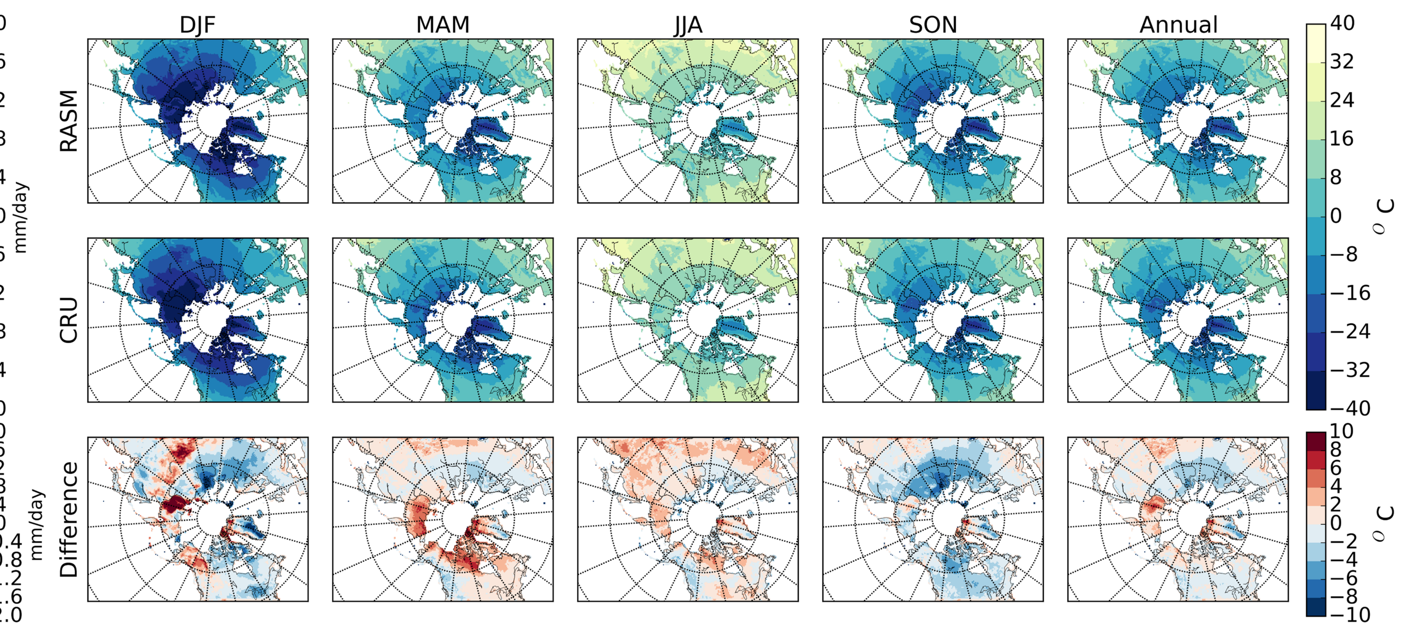
Mean Monthly Water Budget, 1980-2000



RASM Precipitation Compared to CRU, 1980-2010



RASM Surface Air Temperature Compared to CRU, 1980-2010



The Energy Cycle in RASM

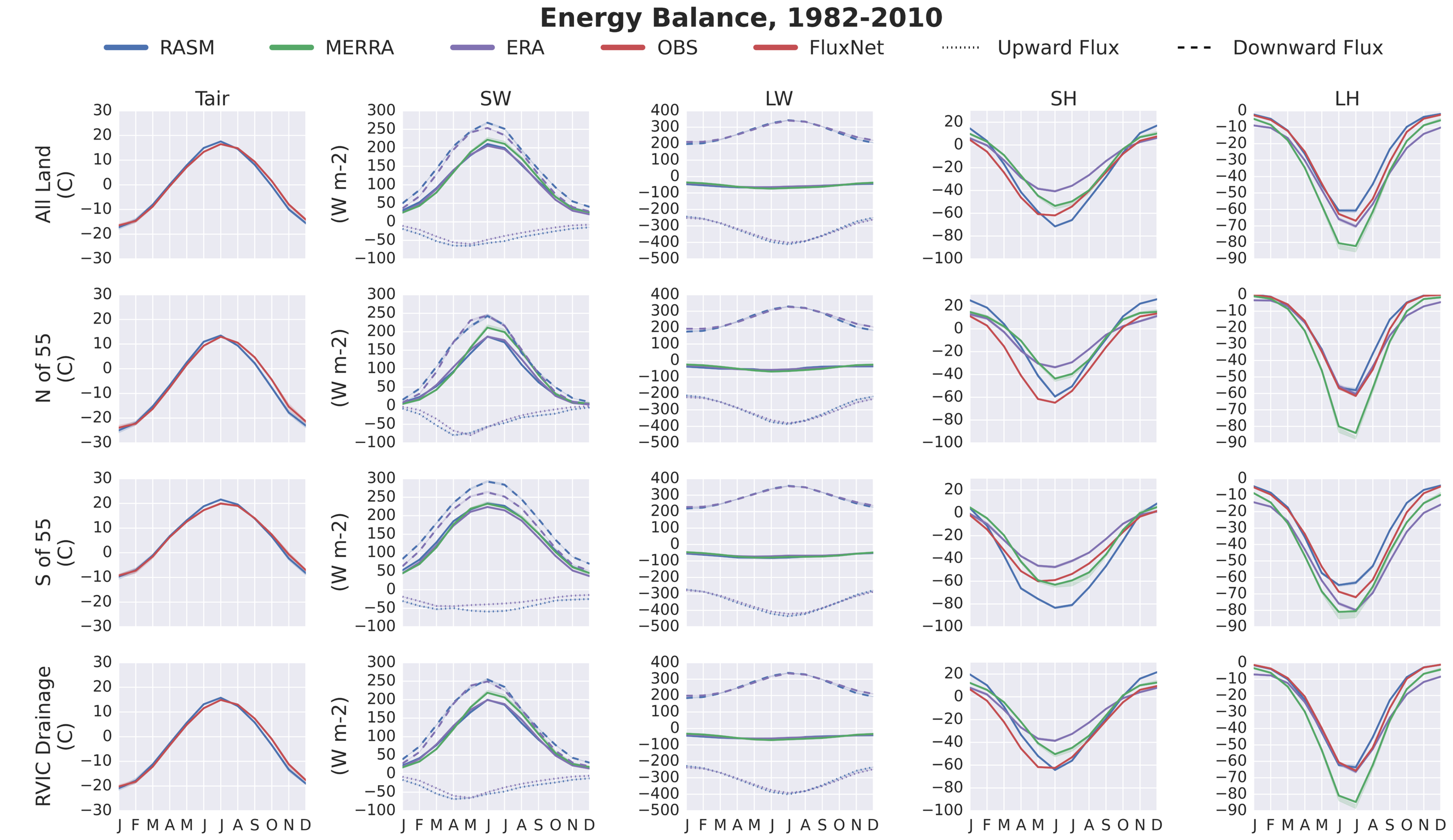
Analysis:

We compare regionally averaged mean-monthly and seasonal (1980-2010) surface air temperature, and energy flux terms between RASM forced with ERA-Interim boundary conditions, MERRA, ERA-Interim, and CRU surface temperature observations. Spatial averaging was performed using the intersection of the RASM, MERRA, ERA-Interim, and CRU masks. The gridded Fluxnet observations are derived from Jung et al (2009), a global, spatially and temporally explicit dataset developed by empirically up-scaling eddy covariance measurements.

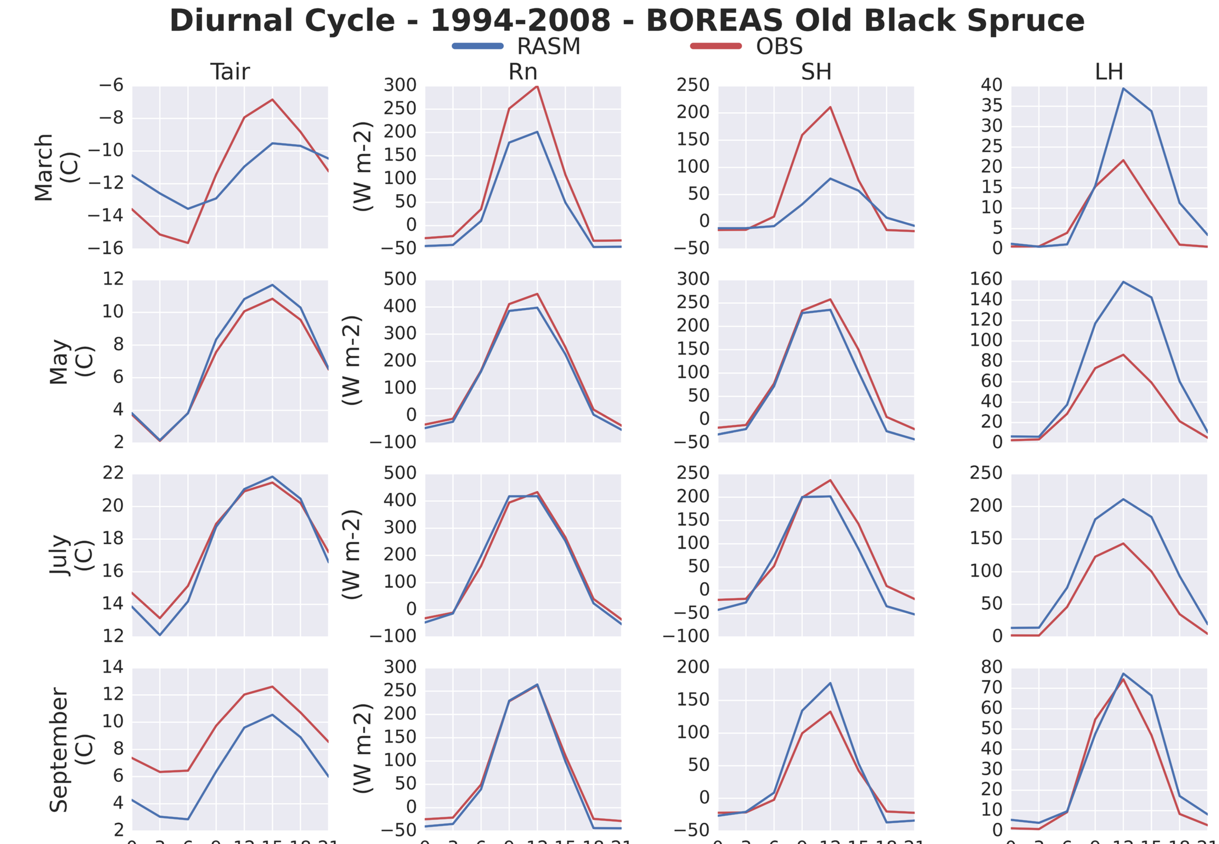
Results:

- Compared to CRU, RASM surface air temperatures have an exaggerated seasonal cycle, with cold biases in the fall and winter, and warm biases in the spring and summer.
- In terms of timing, the seasonal cycle of surface temperature tends to be early, compared to CRU observations.
- Net shortwave radiation is similar between RASM and ERA while MERRA tends to have more at high latitudes during the summer months.
- RASM produces less latent heat flux and more sensible heat flux than both MERRA and ERA. In previous versions of RASM, these differences were substantially larger [See section on *Coupled Land-Atmosphere Processes* for more information].
- At high latitudes (N of 55°), RASM and ERA show similar radiation and turbulent fluxes. The partitioning of these fluxes is quite different in MERRA.

Energy Balance, 1982-2010



Diurnal Cycle - 1994-2008 - BOREAS Old Black Spruce



Turbulent Heat Exchange

Analysis:

The energy and energy budgets are linked through the latent heat flux. We investigate seasonal and diurnal cycles of sensible heat (SH), latent heat (LH), and the Bowen ratio (SH/LH) compared to ground observations (BOREAS Old Black Spruce and upscaled Fluxnet observations) and reanalysis products (NASA MERRA and ERA-Interim).

Results:

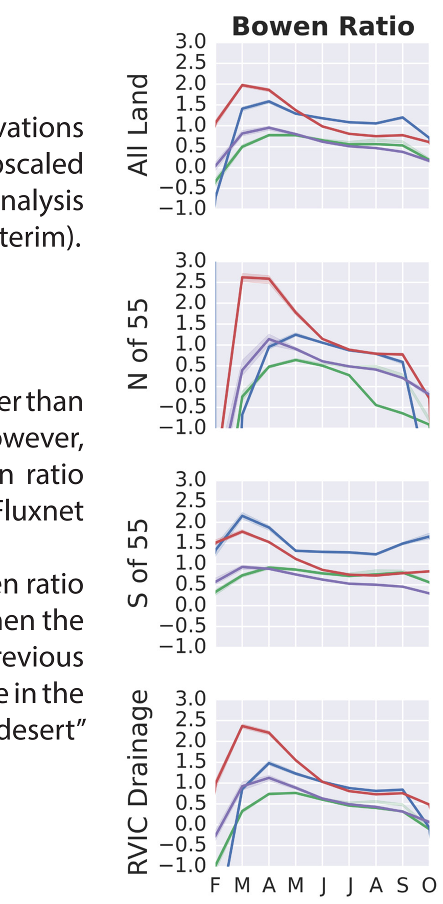
BOREAS Analysis - diurnal cycles

- Air temperature agrees best with grid cell averaged RASM output in the summer whereas the diurnal cycles in spring and fall months differ substantially.
- The RASM latent heat flux is much larger than the observations in the spring and summer.
- The RASM sensible heat flux is much smaller than the observations in the spring.
- Bias in the net radiation and latent heat fluxes during the spring contribute to the lack of agreement between predicted and observed air temperature.

Regional analysis - Bowen ratio

- The Bowen ratio from RASM is larger than both ERA-Interim and MERRA. However, all three underpredict the Bowen ratio compared to the upscaled Fluxnet observations.
- The under prediction of the Bowen ratio is especially clear in the spring when the soils are still frozen the Arctic. Previous studies have coined the large spike in the spring Bowen ratio as the "green desert" effect.

Bowen Ratio



Current Work and Next Steps

Development of New Model Features:

- *Dynamic Vegetation:* The Carbon-Nitrogen Dynamic Vegetation Model (CNDV) is currently being coupled to the Variable Infiltration Capacity land surface model.
- *Land-Ice*: A sub-grid glacier representation that uses an established scaling relationship between glacier volume and area is being added to the Variable Infiltration Capacity model.

Increased Spatial Resolution:

- Future versions of RASM will include higher horizontal resolutions (~25 km for the land-atmosphere and ~4 km for the ocean and sea ice).

Upgrade Model Component Versions:

- Work is currently underway to upgrade the version of VIC in RASM to version 5.0.
- This upgrade will allow for the integrated simulation of permafrost, lakes and wetlands, as well as other cold land processes.
- Infrastructure improvements to the VIC model will include netCDF input/output and multiprocessor support.

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